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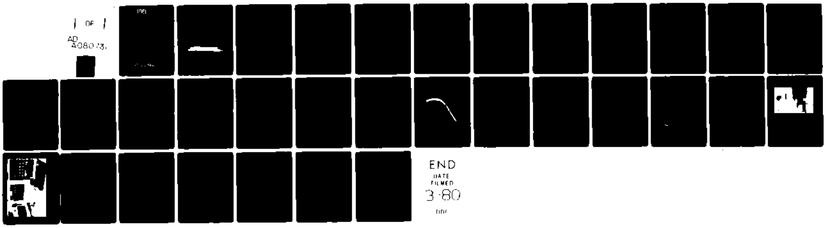

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Final Technical Report

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"EXPLORING NEW CONCEPTS FOR ELUCIDATING PROCESSES OCCURRING IN PYROTECHNIC FLARES AND FOR GENERATING AEROSOL DISPERSIONS"

Submitted

by

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EXPLORING NEW CONCEPTS FOR ELUCIDATING PROCESSES OCCURRING IN PYROTECHNIC FLARES AND FOR GENERATING AEROSOL DISPERSIONS

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BRIEF

Efforts leading to the development of successful techniques for mapping burning pyrotechnic flares are described. An experimental system capable of studying a variety of combustion processes under "noisy" and "smoky" conditions on a time scale appropriate for combusting flare candles is presented. Fundamental investigations designed to elucidate critical design parameters in Babington Nebulizers for application as high density aerosol generators are described.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the support of these investigations by the Naval Air Systems Command, AIR 310C under the technical guidance of Dr. H. Rosenwasser. I also would like to express great appreciation to Dr. B. Douda and his research group at the Naval Weapons Support Center, Crane, Indiana, for valuable advice, as well as R. M. Blunt (Denver Research Institute) for providing flare candles and instruction on safety procedures. Considerable recognition is in order for the extensive efforts exerted by John Algeo, Scott Tilden and David Heine during the course of this project.

Background

Investigation of the complex transient combustion and excitation processes occurring in pyrotechnic flare candles present a number of challenging problems.

Experimental techniques capable of deriving meaningful data from rapidly fluctuating optically dense combustion zones are required. Initial studies (1-3) investigating spectrochemical flames had indicated that one promising approach was to provide contour maps of various species of interests. A new experimental system was subsequently designed to test a variety of concepts and provide detailed knowledge on many design criteria deemed to be important. These investigations (4) sponsored by Naval Air Systems Command under contract N00019-78-C-512 yielded great insight into numerous experimental parameters.

The high-speed mapping system shown in Figure 1, along with the necessary computer algorithms resulted from these efforts to acquire and manipulate data. Basically the system consisted of a custom fabricated scan mirror assembly transferring horizontal scans of successive vertical heights of an emitting flame to a readout monochomator. Synchronization is provided by a laser-photodiode-comparator combination. The resulting signals were conditioned appropriately and fed to a Data General Nova 2-10 through a specially developed interface. (See Reference 4 for a detailed description of this system.)

Numerous computer algorithms both for data acquisition and

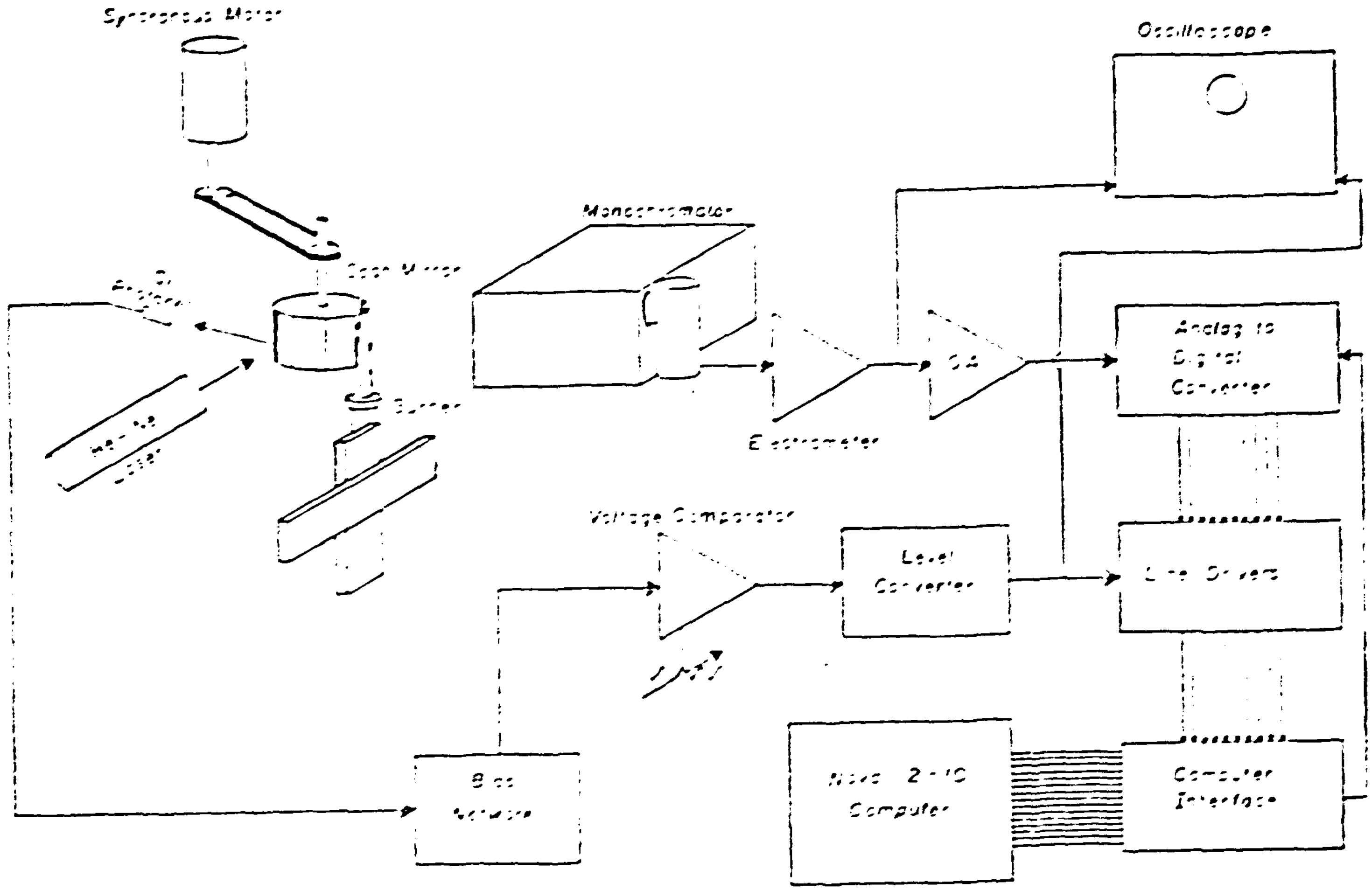


Figure 1: Diagram of the configuration designed to explore the feasibility of mapping conventional flames at high speed.

information extraction were developed and evaluated for use with the system.

The results of these studies strongly supported the following:

(1) High speed x-y and three dimensional mapping of analytical flames was possible.

(2) Highly accurate angles on the spin mirror were not required since angle correction could be accomplished during data reduction.

(3) A variety of smoothing techniques were possible which would be useful in extracting data from optically noisy environments.

(4) With the proper reconfiguration of the experimental system, actual mapping of combusting pyrotechnic flares was a justifiable pursuit.

Experimental

In order to extend the capabilities from analytical flames to the much larger and dirtier flare systems, a major reconfiguration of the entire High Speed Flame Mapping system was required. Since the existing hood/vent system in the University of Arizona's Old Chemistry Building is rather antiquated and provides only a meager amount of suction, a completely independent exhaust system was deemed necessary to handle the high rate of formation of combustion products encountered when burning flares. A special combustion chamber has been constructed from one inch angle iron, aluminum

sheet metal and asbestos (see Figure 2). The size of the chamber (90 X 89 X 75 cm) allows it to be recess mounted in a window frame of the Chemistry Building. A hinged front cover door provides access to the chamber. The floor of the chamber is covered with a layer of low density fire brick. Various observation windows and light baffle tubes can be mounted on the door. A high flow rate "squirrel cage" blower fan rated at approximately 180 cubic feet per minute is mounted on the top of the chamber to exhaust combustion products.

To ensure that the test chamber would be adequate for safe flare combustion and be capable of handling the smoke, soot, and other products, a series of test firings were conducted in a desert area. With the exhaust blower operating, candles were ignited. No major problems were encountered concerning the test chamber's safety. However, these tests indicated that a larger capacity blower might be desirable in the future, particularly if large candles were to be investigated.

Additionally, these initial test firings suggested that for certain types of investigations, some degree of light baffling might be desirable to reduce the level of smoke and particulate combustion products in the observation optical path.

A holder for supporting test candles has been fabricated from Armco 1100 machinable ceramic. This holder is mounted on a fire brick slab (see Figure 3). Unfortunately, a properly oriented window was not present in the lab where the High Speed Flame Mapping System (funded by the Office of Naval Research) and the

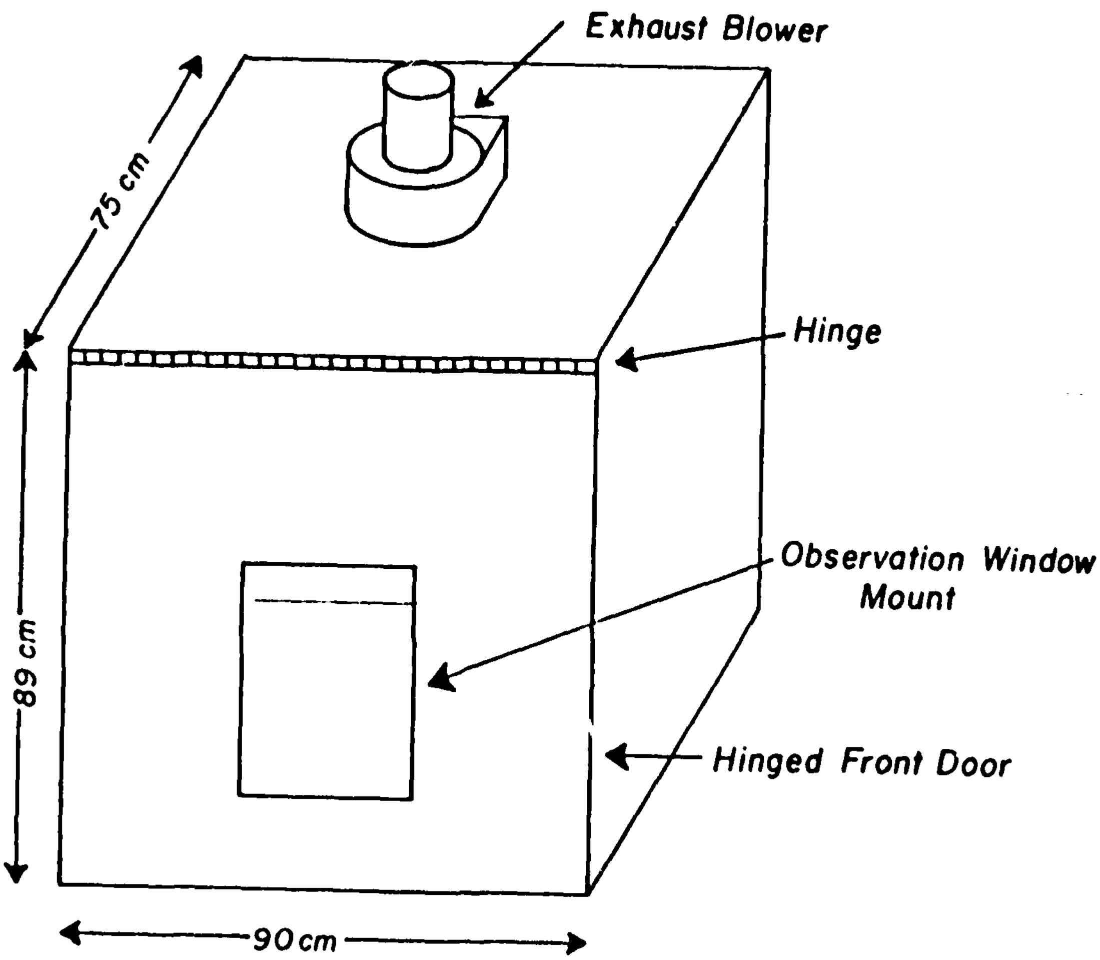


Figure 2. Pyrotechnic Flare Test Chamber

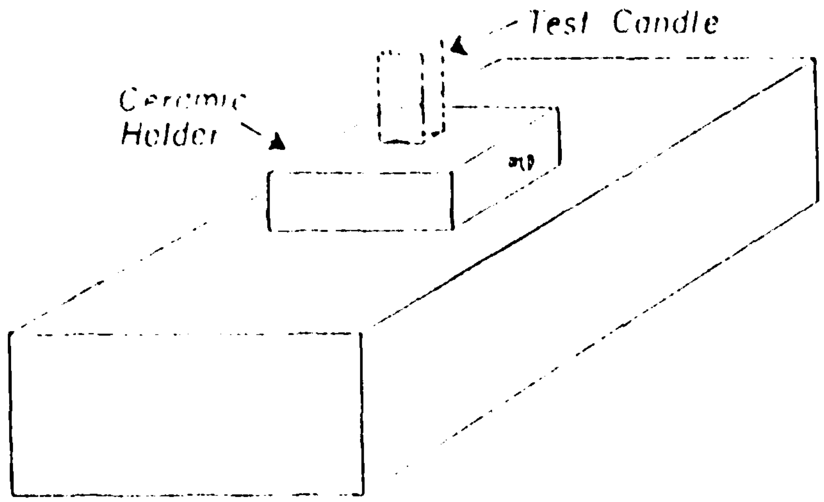


Figure 3. Ceramic mount for holding test candle.

computer system which operates both experimental systems were located. Both experimental systems, the computer and related peripherals have since been moved into a different lab. This move was not an insignificant task, since many new, longer interface cables had to be fabricated, etc.

Numerous modifications were also made in the optics of the High Speed Mapping System (see Figure 4). The optical system now consists of a 40.6 cm diameter, 20 cm focal length parabolic light collection mirror set at a distance of 125 [illegible] from the test candle. Photons are first transferred to a 10 cm focal length, 10 cm diameter convex mirror, then through a center aperture in the 40.6 cm parabolic mirror, to the scan mirror assembly which deflects the photon beam toward the readout monochomator. The focal lengths are chosen so that images of the flare are produced on the entrance slits of the monochromator. A one-millimeter pinhole mask is placed just in front of the entrance slits. The configuration causes an image of the flare to be swept by the pinhole slit combination. As each successive mirror spins by, the image is offset vertically. During the passage of a single image, a series of data points are acquired (i.e. one horizontal scan slice). The next mirror will provide the next horizontal scan slice, etc. The total use of mirrors for transfer and imaging offers several advantages, including the ability to perform studies from the infrared to the ultraviolet, requiring only substitution of a different monochromator and detector, as well as the operational convenience of visual alignment.

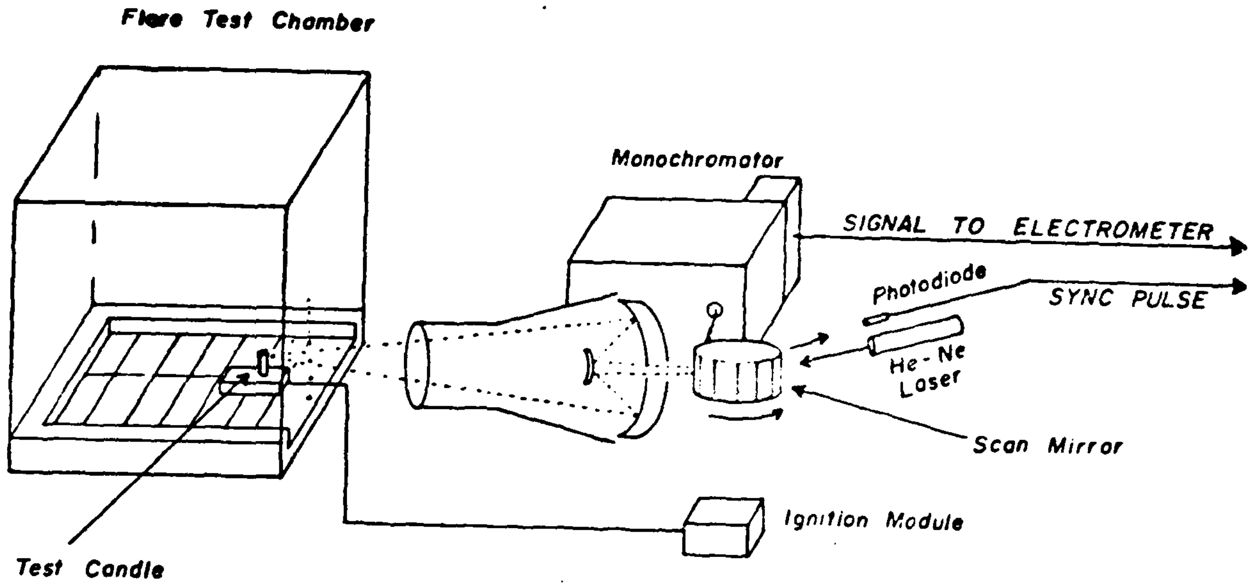


Figure 4. High Speed Flame Mapping System in Pevised Configuration for Mapping Pyrotechnic Flare Candles.

The electronics have been modified through the addition of a real time clock and status gating circuitry (see Figure 5).

Flare ignition is accomplished using a ten volt, thirty amp step down transformer hooked to a 0.25 mm diameter tungsten wire. The first fire compound employed is a mixture of potassium nitrate and sucrose (occasionally, a little magnesium is added). A linear "cigarette" type of burn is promoted through coating the sides of the test candle with epoxy, using techniques suggested by R. M. Blunt (Denver Research Institute). While this is not one hundred percent effective, it has been found to help considerably.

To ensure safety, David Heine and M. B. Denton visited R. M. Blunt's laboratory at Denver Research Institute and received training in the procedures for safely handling and burning flare candles. Denver Research Institute also provided quarter section IR emitting test candles (1.5 X 2.0 X 7.5 cm wedges) for use in these studies.

Initial flare studies were designed to test and optimize the overall experimental system. These tests were conducted in the visible since the system was known to function in the visible, and visual observation of the light paths is more easily accomplished. The system is currently capable of generating flare emission profile maps such as those of Figures 6-8. These maps show the emission profile of a flare at approximately six, nine, and twelve seconds into a burn.

To allow acquisition of a reasonable number of raster scans,

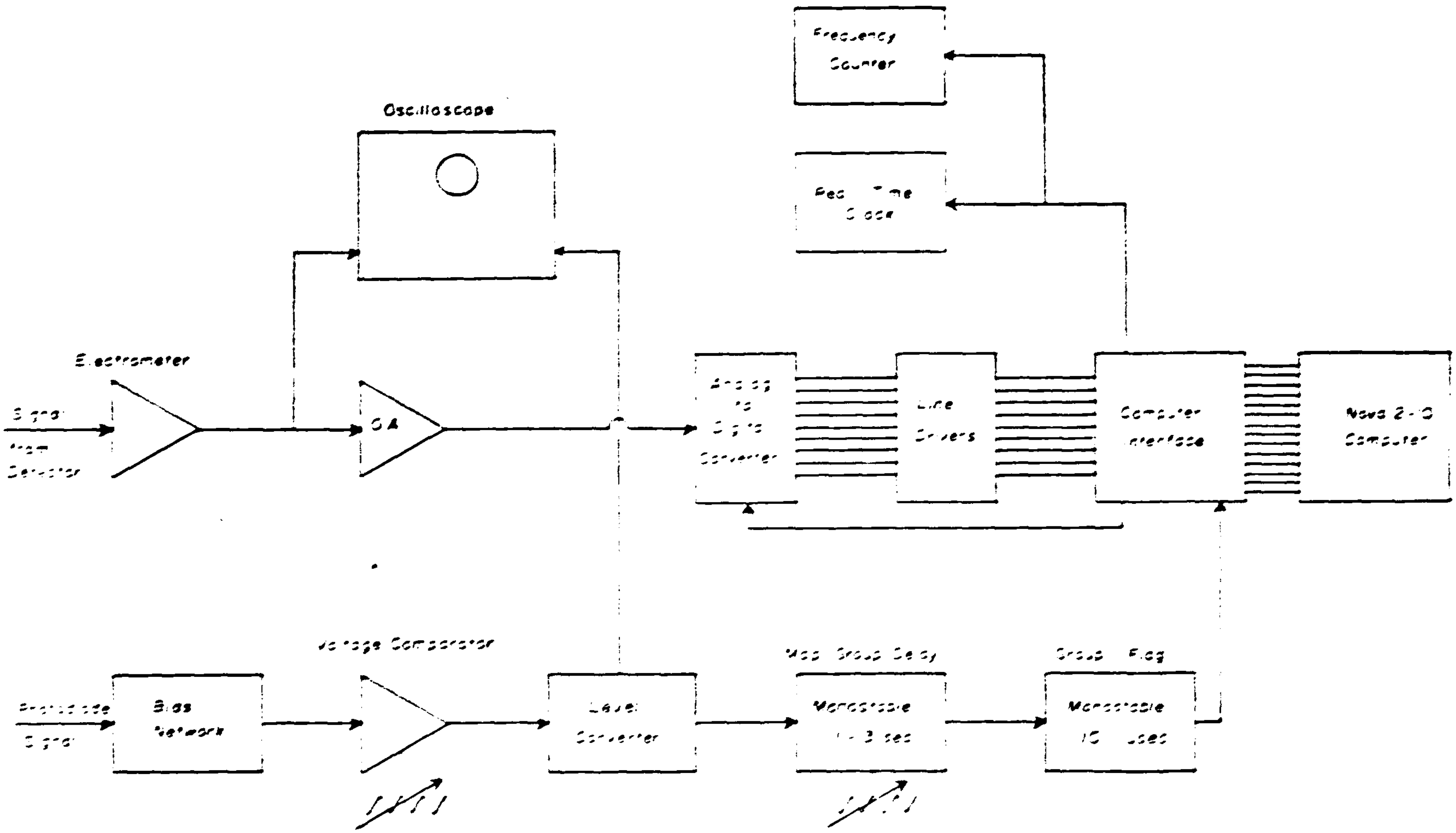


Figure 5. Revised electronic system used for High Speed Flame Mapping.

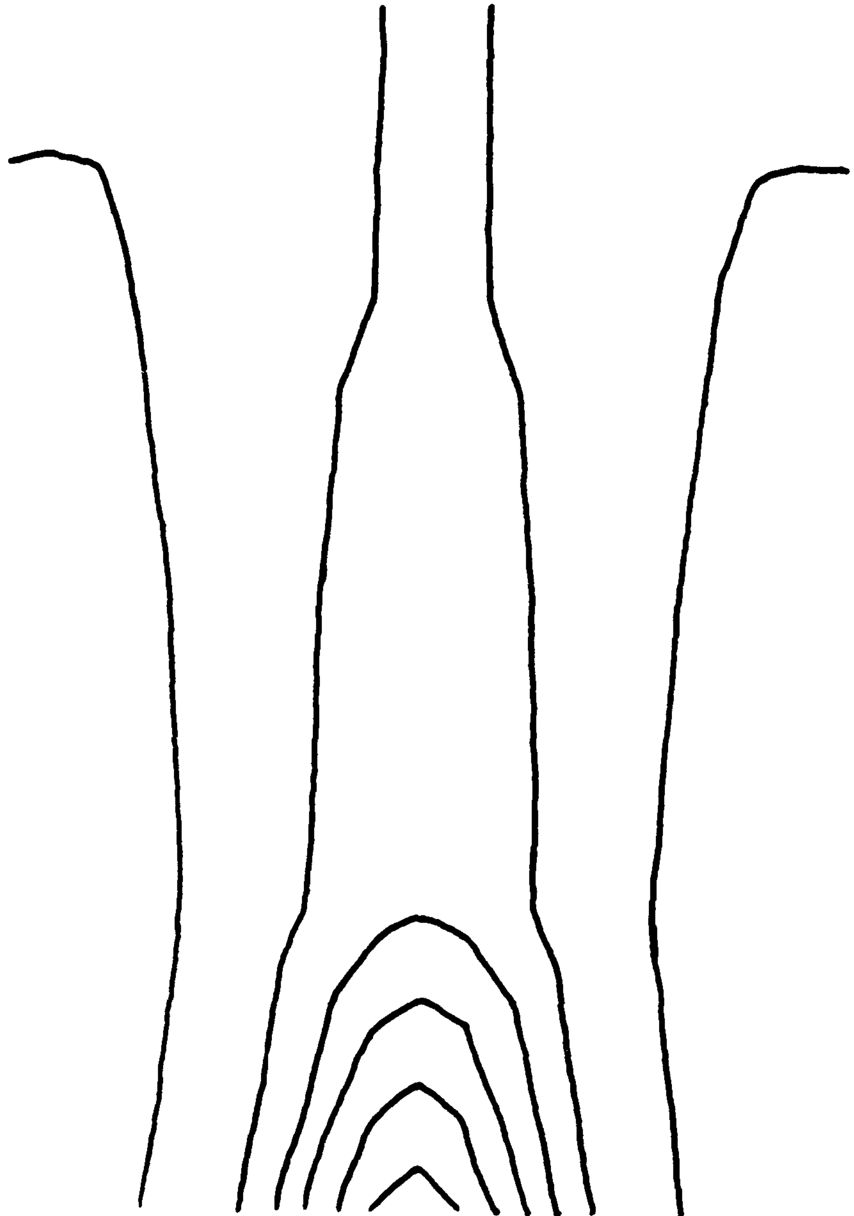


Figure 6. A flame map taken approximately 6 seconds after ignition. Conditions: Wavelength 589.2 nm; Slit: 70μ wide by 2 mm high; Photomultiplier voltage 550; Electrometer 0.1 x 10^{-7} A full scale; Data rate 17.5 kHz; 2700 points/scan. Contour interval: 0.25v.

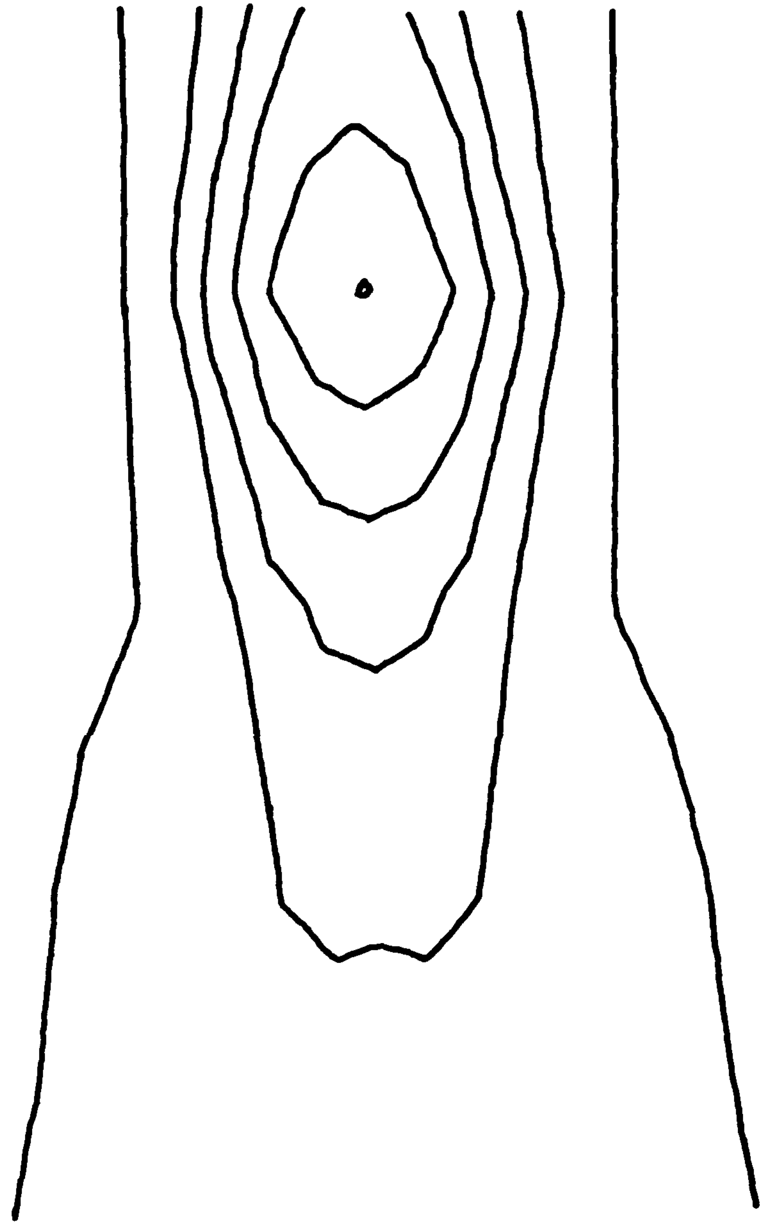


Figure 7. The same flare after approximately 8.5 seconds.
Conditions: Wavelength 589.2 nm; slit: 70μ wide by 2 mm high;
Photomultiplier voltage 550; Electrometer 0.1×10^{-7} A full scale;
Data rate 17.5 KHz; 2700 points/scan. Contour interval: 0.25v.

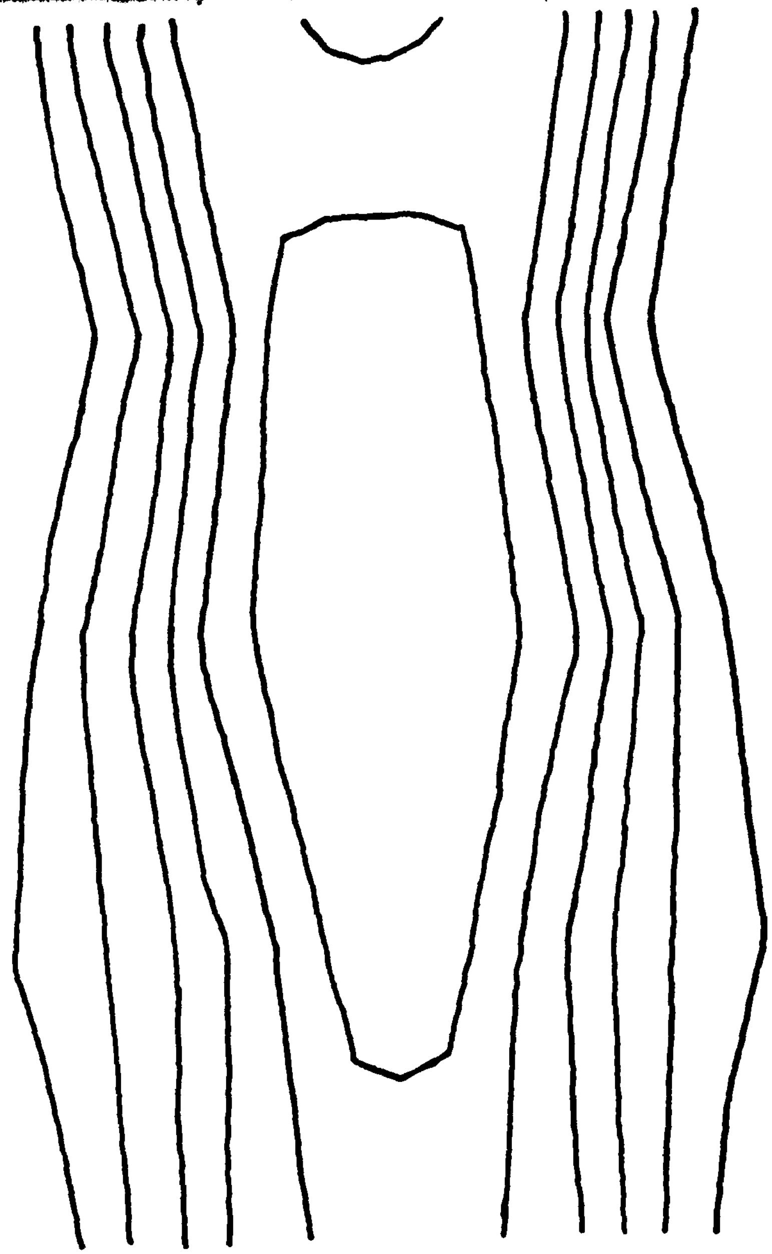


Figure 8. The same flare after approximately 12 seconds.
Conditions: Wavelength 589.2 nm; Slit: 70μ wide by 2 mm high; Photomultiplier voltage 550; Electrometer 0.1 x 10^{-7} A full scale; Data rate 17.5 KHz; 2700 points/scan. Contour interval: 0.25v.

some means had to be found to transfer the data comprising several raster scans to mass memory (Xebec dual drive floppy discs) without taking an excessive amount of time. The standard Xebec support software was found to be unacceptably slow.

In order to allow the collection of sufficient information during a flare burn, a program was developed which accumulates successive raster scans in core memory and then dumps all of the data to the disk. This program can acquire up to 8 raster scans at any speed up to the limit imposed by the rotational speed of the scan mirror. These 8 scans are currently dumped onto the disk in approximately 20 seconds. The existing map plotting routines could not accept data written at high speed because of the data's binary format. A program which performs the necessary format conversion, and also can be employed to smooth the data, has been developed.

While it is still unclear if Abel Inversion type algorithms (see Reference 4 for a background description on use of the inverted Abel integral for generating three dimensional profile maps from two dimensional circularly symmetrical data) will be usable with pyrotechnic flares, the ability to determine the three dimensional spatial distribution of emitting species would be a major asset. Considerable effort has been expended during this contract period evaluating how noise on the signal affects the precision of the resulting three dimensional map. A variety of algorithms have been investigated using flame map data onto which varying amounts

of random "noise" have been superimposed.

The original proposed plan for extending spectral coverage into the infrared region involved conversion of the existing monochromator to the infrared region through substitution of an IR grating and an appropriate high speed detector. While this approach had serious drawbacks, sufficient funding was not available to purchase a commercial infrared monochromator. However, during the contract period a government surplus Beckman IR-8 infrared spectrometer was acquired from Ames Laboratory.

While the response speed of this instrument was far too slow for the desired application, it did offer several significant capabilities over those that would result from the modification of our existing monochromator, including reliable wavelength calibration, improved optical throughput efficiency, and the ability to retain the existing monochromator for use in the ultraviolet/ visible spectral region.

The spectrometer was initally checked out and made operational in its original modes. The very slow response speed detector in the IR-8 was subsequently replaced with a liquid nitrogen cooled, high-speed (less than ten nanosecond risetime), gold-doped germanium detector (Santa Barbara Research Center model 19399, Goleta, CA), which has reasonable spectral response (5) from 2 to 8 microns (see Figure 9). The required vertical mounting geometry was achieved through use of a parabolic folding mirror and a variety of mechanical modifications to the instrument's optical bed and case.

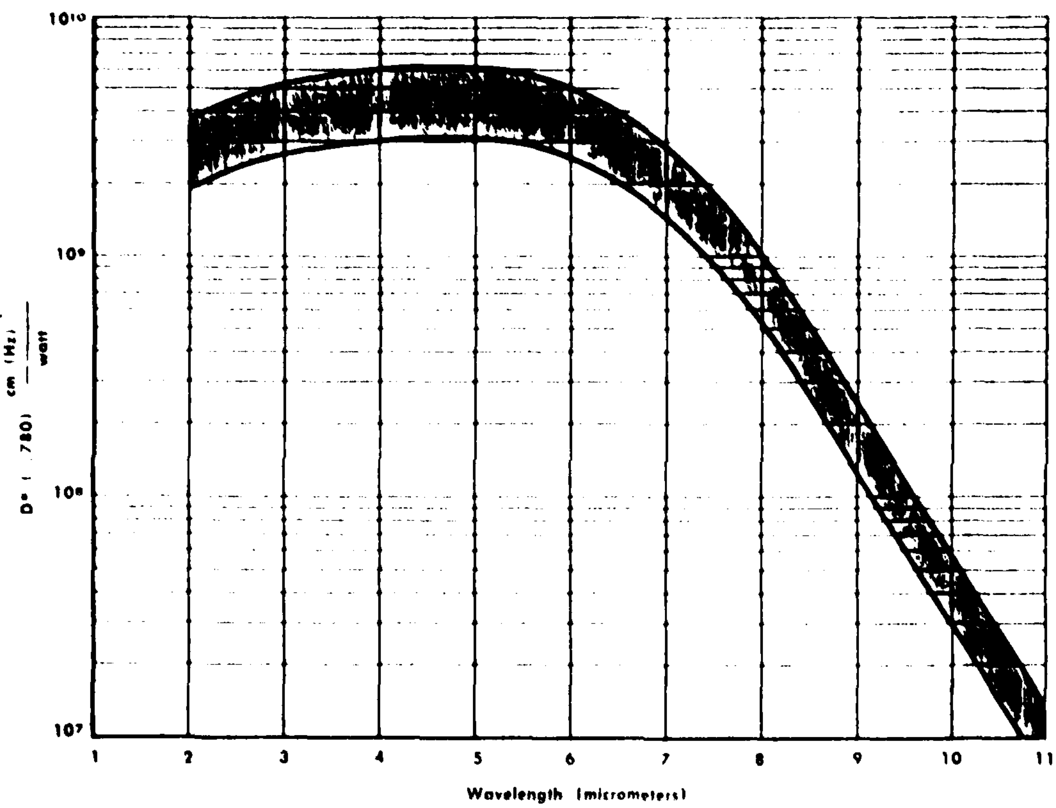


Figure 9. Spectral Response for the Gold-Doped Germanium detector.

During the course of these modifications, it was determined that the retention of the filters which prevent multiple order overlap would be less than trivial. However, since this detector has a limited region of spectral response, multiple overlap should not be too great a problem. Additionally, external filters can be added if the need should arise.

A shielded biasing network has been constructed which is comprised of a 0.1 fd. bypassed Lambda LH 124-0405 zero to forty volt ultra low ripple supply feeding a 3 megohm 1% film resistor in series with the high speed detector. The voltage signal across the detector was initially converted to a current through a second 3 megohm 1% film resistor and fed to a Keithley Model 417 high speed picoammeter. The resulting configuration allowed selection of a particular wavelength which will be mapped using the IR-8's spectral calibration. Check-out of the system has shown that the detector works, but was approximately two-orders of magnitude below rated typical sensitivity and has a response curve differing from that specified (it should be noted that the detector is on loan from Lawrence Livermore Laboratory at no cost to Naval Air Systems Command). However, in view of the intense emission signal from the flares under study, this was not expected to be a major limitation for initial tests (ultimately a different detector may be required). Alignment of the system using a more conventional continuous source proved to be a problem. Additionally direct (d.c.) coupling of the detector to the readout electrometer, operational amplifier, and analog to digital converter resulted in a major problem.

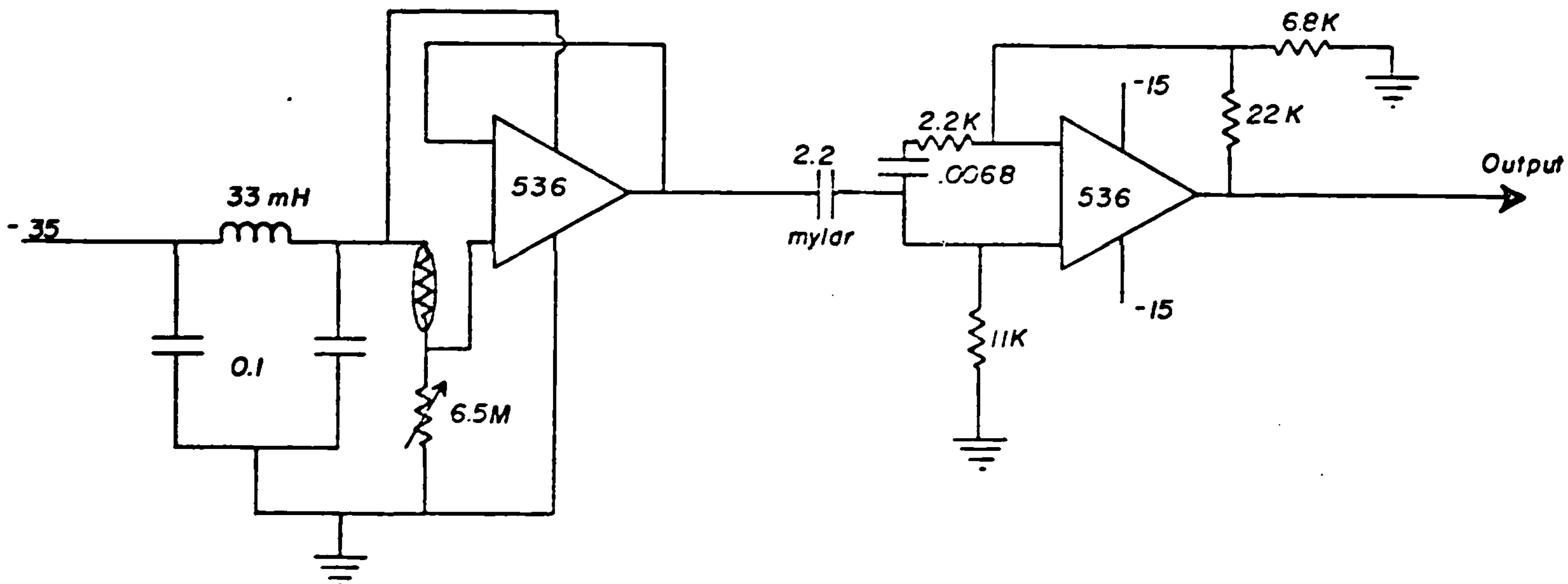


Figure 10. Schematic of the special a.c. coupled preamplifier developed to reject long term drift in the detector.

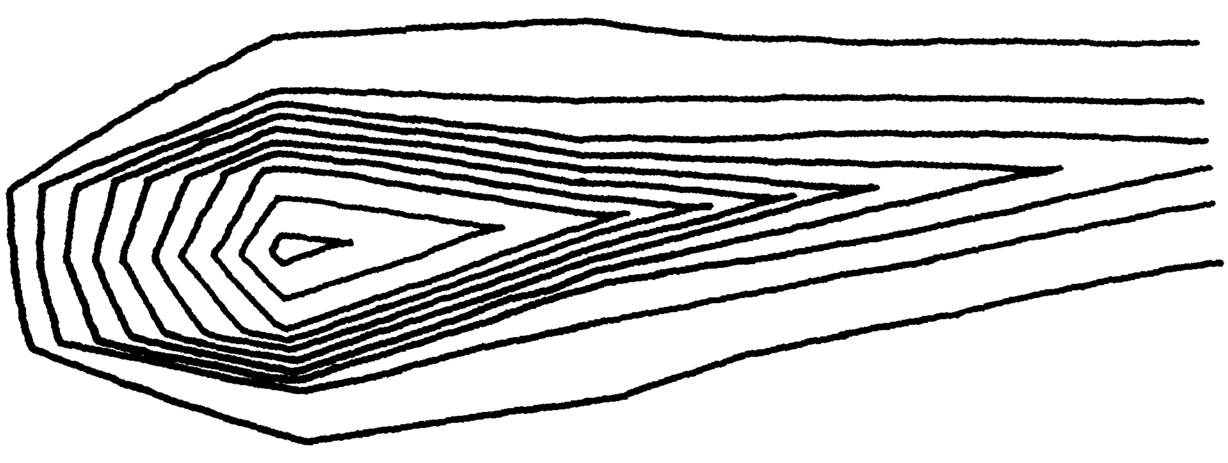
Since the background level of the detector slowly drifts, problems associated with limiting either the electrometer or analog to digital converter were encountered.

To eliminate this long term drift, a special a.c. coupled preamplifier was designed and constructed. A schematic diagram of the circuitry is presented in Figure 10. Field effect transistor operational amplifiers are employed. The RC time constant is chosen to allow amplification of events occurring on time scales faster than 24 milliseconds. Consequently, at the current rate of revolution of the ten facet scan mirror, signals arising from the scanned region are observed while long term changes (drift) are rejected.

Using these modifications, tests were made demonstrating the ability to obtain emission maps of an infrared heating element. Figure 11 shows a map of a lightbulb at 3.2 microns. Subsequent studies have resulted in infrared maps of pyrotechnic flares. An example is given in Figure 12.

Due to the considerable amount of effort expended in the area of development of capabilities for pyrotechnic flare mapping, much less time was directed in the area of aerosol generation. However, studies were conducted which provide a considerable amount of new insight into the critical parameters governing the aerosol density produced by Babington principle nebulizers.

A series of studies to evaluate parameters affecting aerosol generation rates have been conducted. The relative generation rates for a variety of configurations were monitored by measuring flame emission



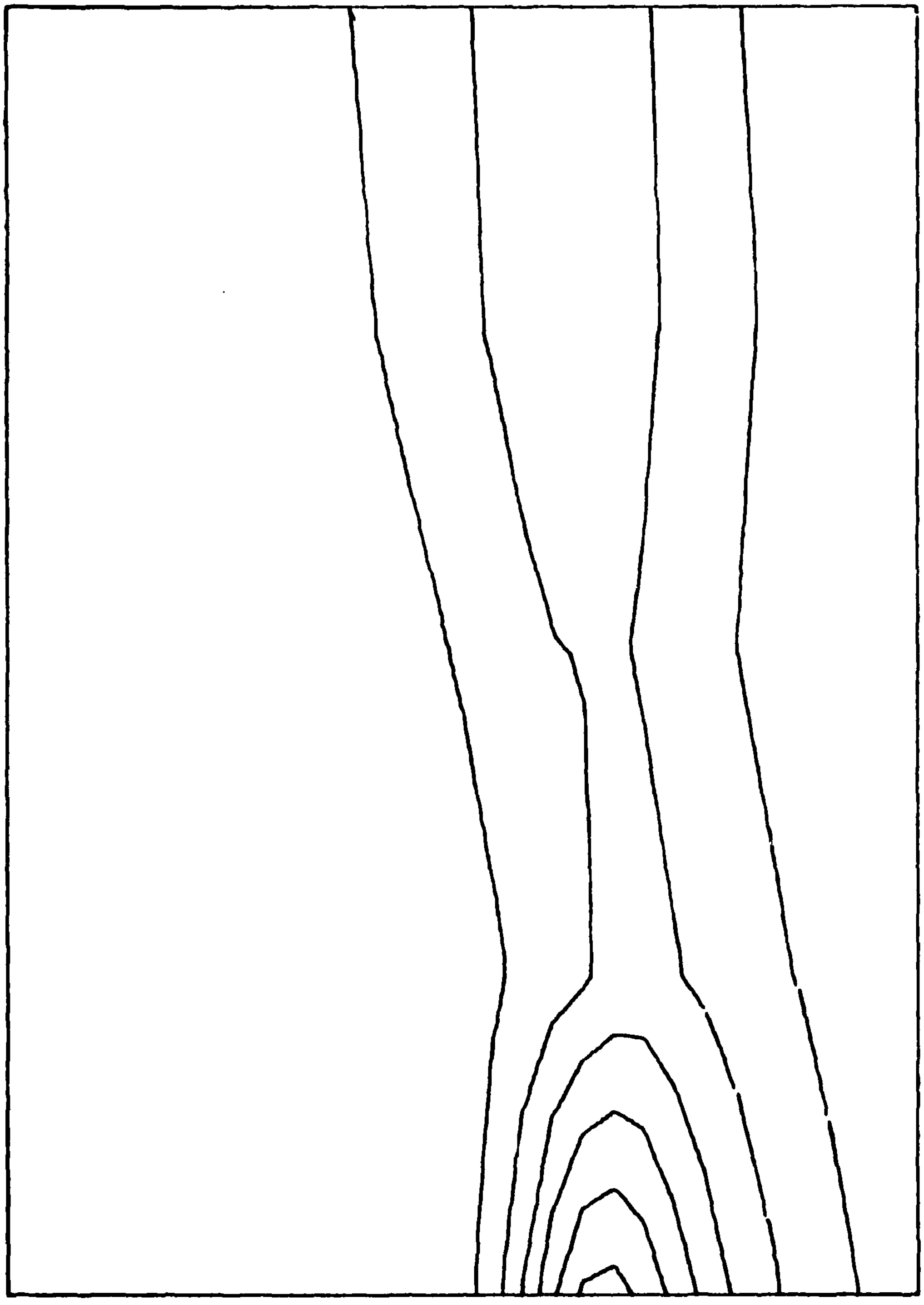


Figure 12. Infrared map of a flare

Figure 13: Combustion of a pyrotechnic flare in the test chamber of the high speed mapping system. The scan mirror assembly and light collection telescope are in the foreground. The helium-neon synchronization laser is to the right.

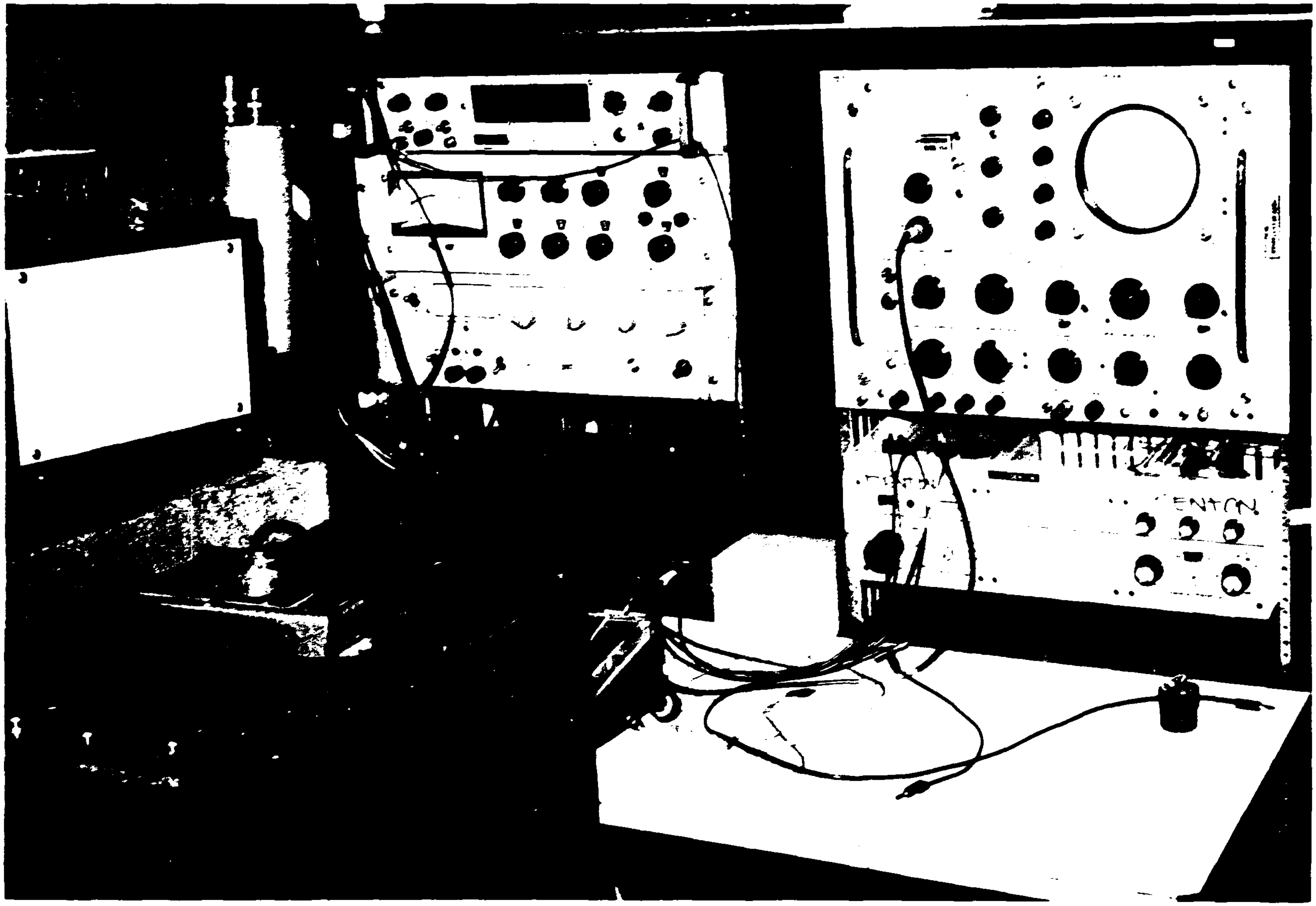


Figure 14: Electronic console used with the high speed pyrotechnic flare mapping system.

signals produced when the aerosol containing an appropriate element (generally sodium or calcium) was introduced into an air-acetylene flame. Figure 15 contrasts the original Babington principle nebulizer (top) with the intermediate designs and new concepts investigated during these studies. A variety of channel flow configurations as well as the Cup types of devices have been evaluated.

Optimum aerosol generation from a Babington principle nebulizer is obtained when the devices are operated at reasonably high pressure drops. This effect can be seen in Figure 16 comparing a single hole channel flow with a dual hole over/under configuration. Solution flow rate requires optimization whenever the operating pressure is changed. However, a wider range of solution feed rates can be tolerated at higher pressure. This effect can be seen in Figure 17 where virtually the same aerosol generation rate is observed between 20 and 65 ml/min solution rate for the high pressure case while a definite peak is observed at approximately 17 ml/min for the lower pressure operation.

Summary of Effort

A considerable amount of progress has been made during the course of this project. The entire high speed flame mapping system has been redesigned to allow study of pyrotechnic flare candles. An appropriate combustion chamber has been assembled and maps of burning flares obtained. The spectral observation region has been extended into the infrared. The resulting capabilities include the

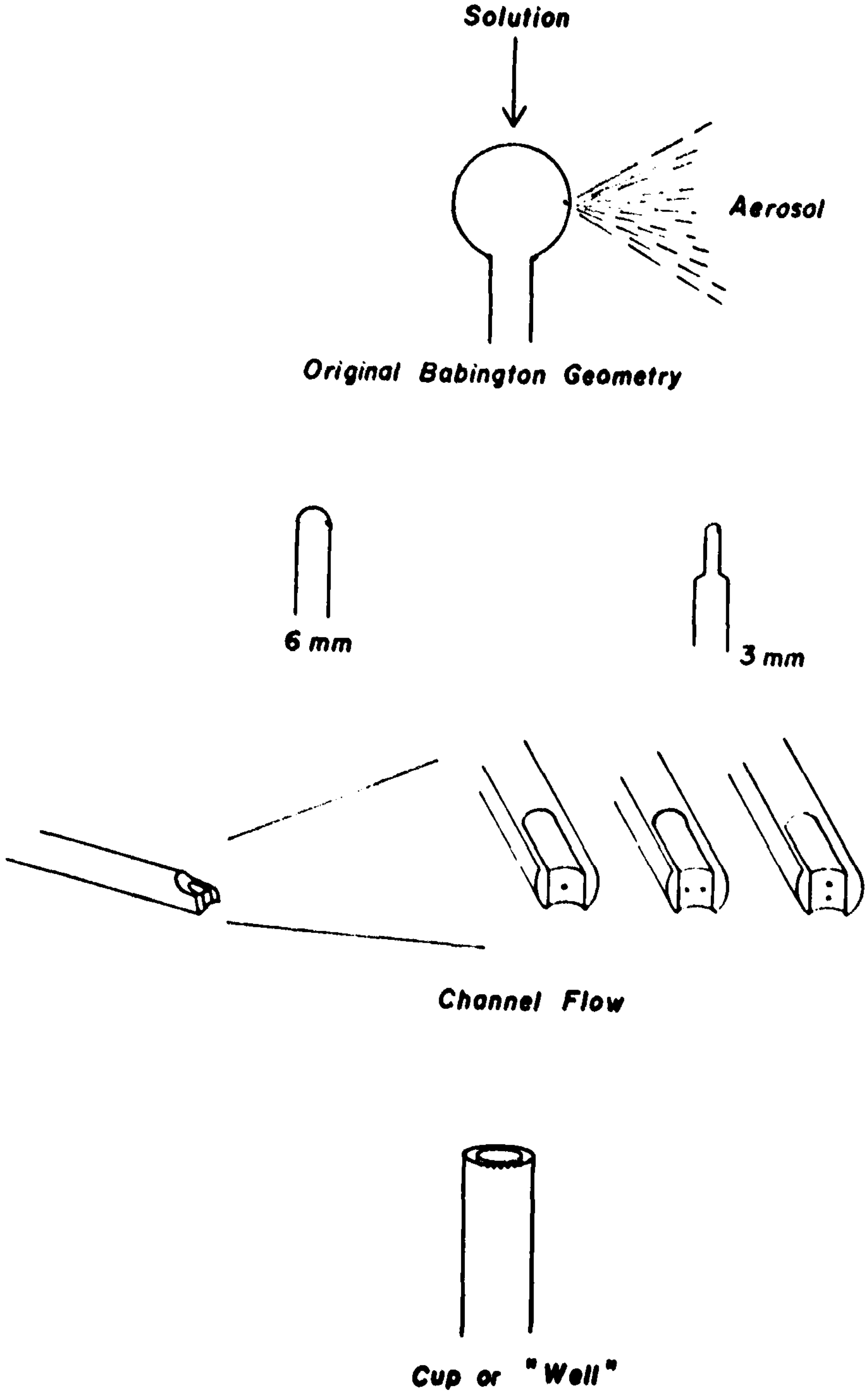


Figure 15. Contrasts between the original Babington principle nebulizer (top) and intermediate designs and new concepts.

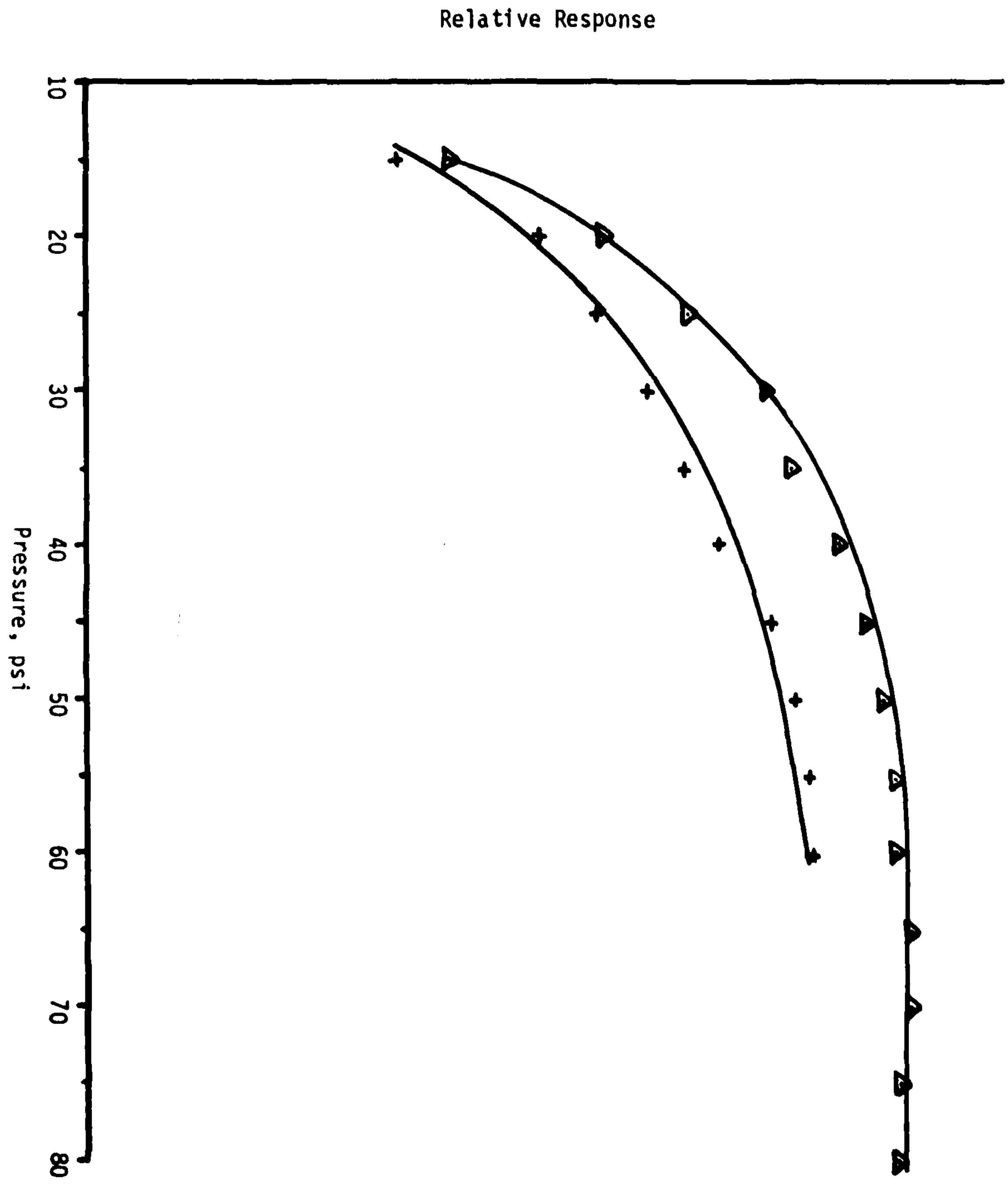


Figure 16. Response given by two channel flow tips versus pressure drop. Solution flow rate .41ml/min. Upper curve: tip having a single 0.34 mm orifice. Lower curve: tip having two 0.34 mm orifices in an over/under configuration.

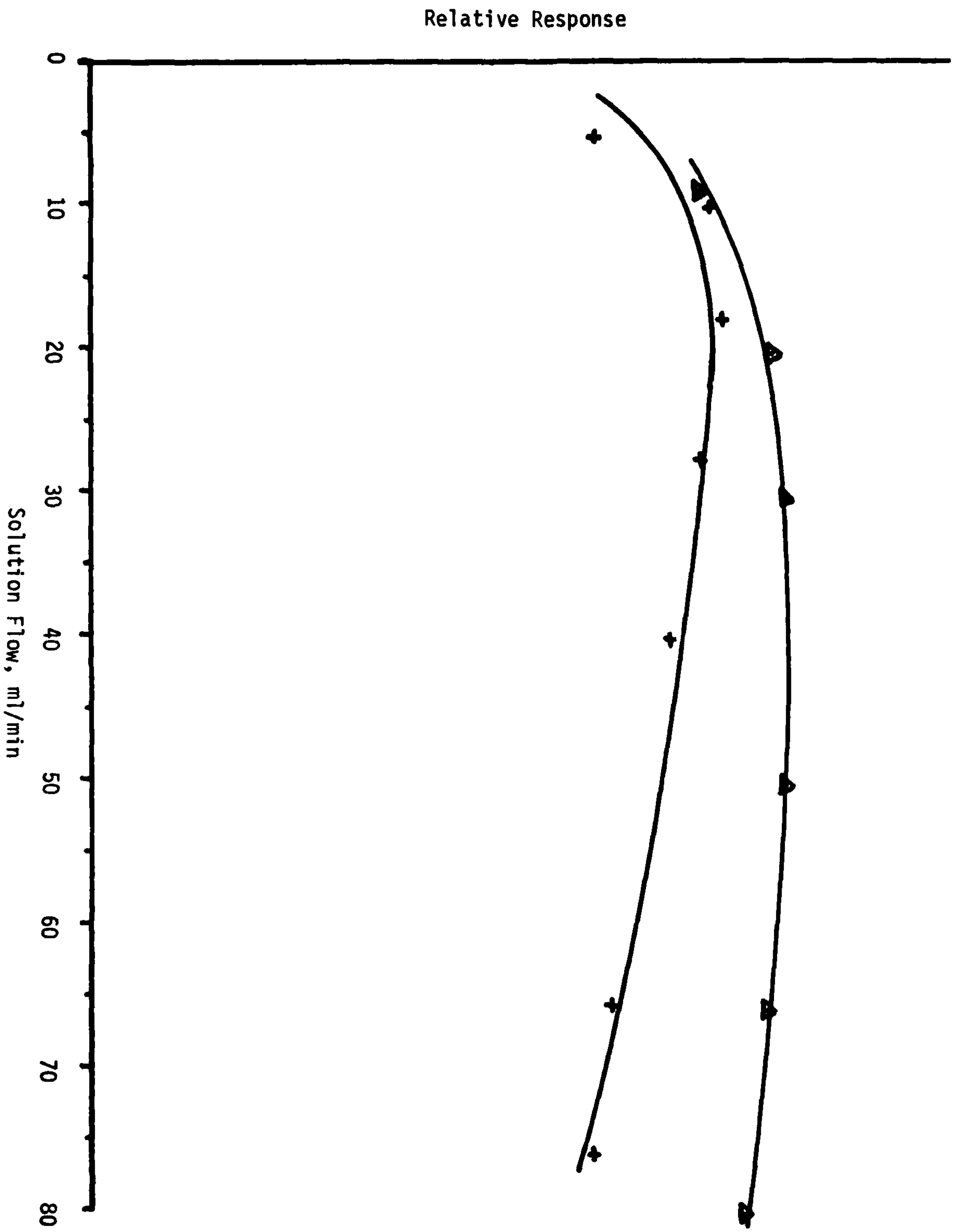


Figure 17. Response given by a channel flow tip having a single 0.34 mm orifice as a function of solution flow rate. Upper curve: 80 psi pressure drop over the orifice. Lower curve: 25 psi pressure drop.

ability to rapidly map the changing emission profile at a selected wavelength, providing data describing the changing distribution of the observed species. Observation of not only the desired emitting species, for example in the infrared, but also the various possible precursors and contributors (ultraviolet and visible emission) should yield considerable insight into the mechanisms governing production and excitation of the desired species. This improved understanding of the physical phenomena governing the systems should be beneficial in development of improved pyrotechnic devices. Investigations have been conducted into the fundamental aspects of Babington principle aerosol generation resulting in data which shed insight on geometrical and operational parameters.

The total number of man hours has considerably exceeded 960 hours. All Naval Air Systems Command funds have been spent.

1. M. W. Routh and M. B. Denton, Appl. Spectrosc., 30, 344 (1976).

2. M. B. Denton and M. W. Routh, Proceedings of the Fifth International Pyrotechnics Seminar, Denver Research Institute (1976).

3. M. B. Denton, J.D. Algeo, and D. L. Heine, Research Program Review, Naval Air Systems Command, Research and Technology Group. Energy Conversion, I. Non-Propulsive Aspects B. Pyrotechnics, November, 1977.

4. M. B. Denton, "Investigating Mapping Techniques for Elucidating Processes Occurring in Pyrotechnic Flares and Their Flame Analogs", University of Arizona Final Technical Report N00019-76-C-510 Naval Air Systems Command.

5. Santa Barbara Research Center, Technical Data Manual page 8.